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ATS-6 MILLIMETER WAVELENGTH PROPAGATION EXPERIMENT

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16. Abstract

An empirical relation for path diversity gain as a function of terminal separation distance and single site fade depth is presented. This relation is based on existing 15.3 GHz ATS-5 attenuation data and 16.0 GHz radiometric temperature data for earth-space propagation paths. Preliminary 30 GHz ATS-6 diversity data are presented and are found to agree well with this empirical relation.

The current status and summary of operations are also reviewed.

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Footnote:

Parts I and II of this report were presented at the USNC/URSI meeting, Urbana, Illinois, 3-5 June 1975. Part I of this report has also been submitted to the IEEE Transactions on Antennas and Propagation for publication.

I. EMPIRICAL DIVERSITY GAIN RELATION

Only a limited amount of diversity gain data exists for millimeter wavelength earth-space propagation paths. These data, consisting of measurements performed by The Ohio State University and Bell Telephone Laboratories, were collected and presented in an earlier publication [1]. The OSU data were obtained using the ATS-5 15.3 GHz downlink for attenuation measurements; and the BTL data were generated from 16 GHz radiometric temperature measurements along a nominal ATS-5 propagation path. In both cases the ground terminals were separated along a baseline oriented in approximately the NW-SE direction; the nominal look angles were 220° azimuth and 35° elevation. Even though these data were collected in different locations, the OSU data in Ohio and the BTL data in New Jersey, and over different time periods, the resulting diversity gain data were remarkably consistent.

Diversity gain is defined here as the difference between the path attenuations associated with the single terminal and diversity modes of operation for a given percentage time. Thus, diversity gain, G, is a function of the single terminal fade depth, A, as well as the terminal separation distance, D.

These data were used to generate an empirical relationship for diversity gain as a function of both separation distance and single terminal fade depth. First, it was recognized that the diversity gain data, Fig. 1, behaved as

$$(1) \qquad G = a(1-e^{-bD})$$

for each value of single terminal fade depth. Consequently, a minimum RMS error fit was performed for each fade depth; this procedure yielded a family of coefficients, a and b, which depended only upon the fade depth. These coefficients, Figs. 2 and 3, were also fit to closed form analytic expressions:

$$(2) \qquad a = A - 3.6\ (1-e^{-0.24A})$$

$$(3) \qquad b = 0.46\ (1-e^{-0.26A})$$

where G and A are expressed in dB and D is expressed in kilometers. Now, using Eqs. (1), (2), and (3), diversity gain was calculated as a function of terminal separation distance and single terminal fade depth. The results of these calculations are shown in Fig. 1; it may be seen that the agreement between the empirical calculation and the data points is at
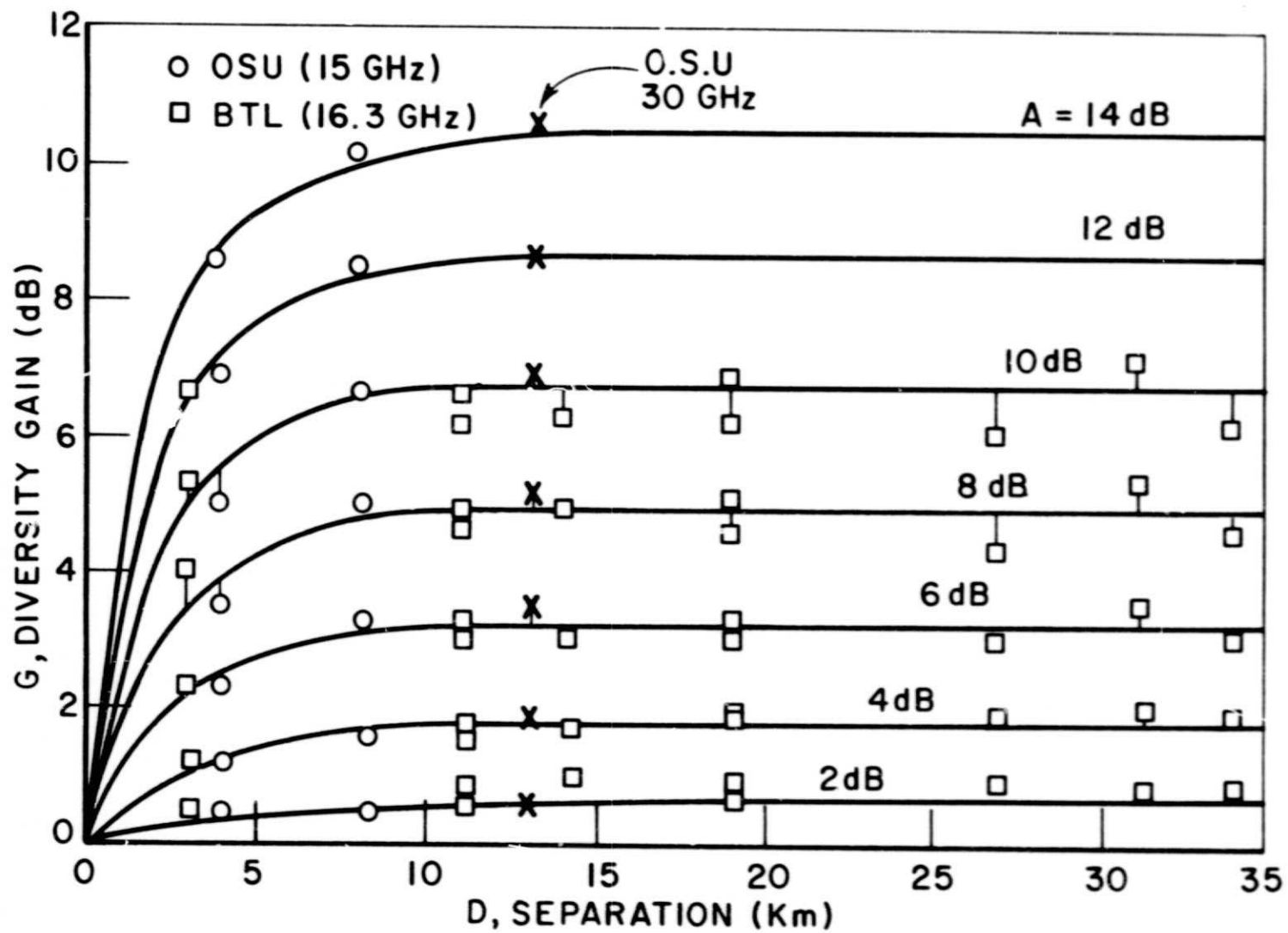
1

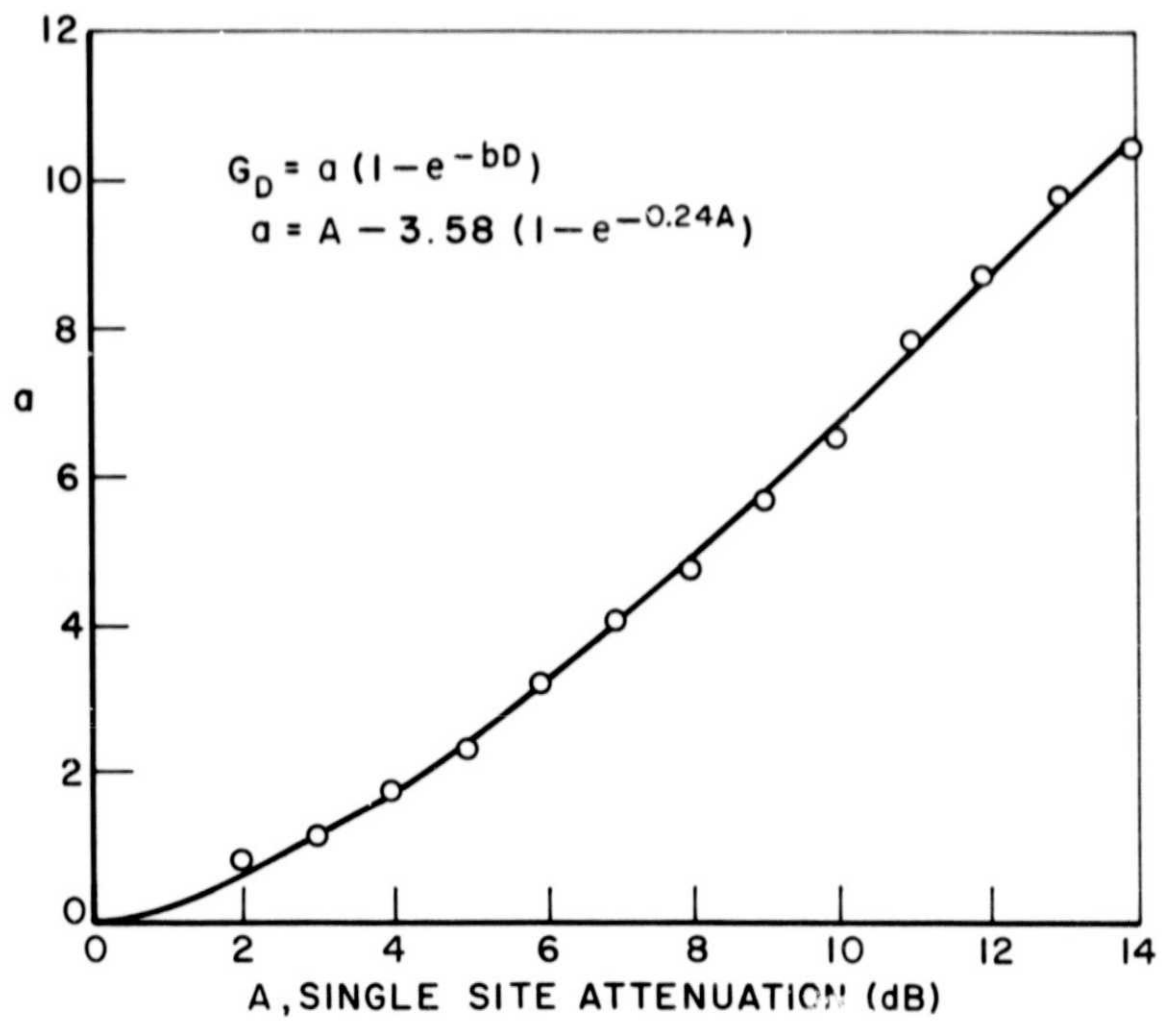Fig. 1. Diversity gain versus terminal separation distance.

Fig. 2. Coefficient a versus single site attenuation, A.

The figure shows a plot with axes:
- Y-axis: b, ranging from 0 to 0.5
- X-axis: A, SINGLE SITE ATTENUATION (dB), ranging from 0 to 14

Equations shown on the plot:
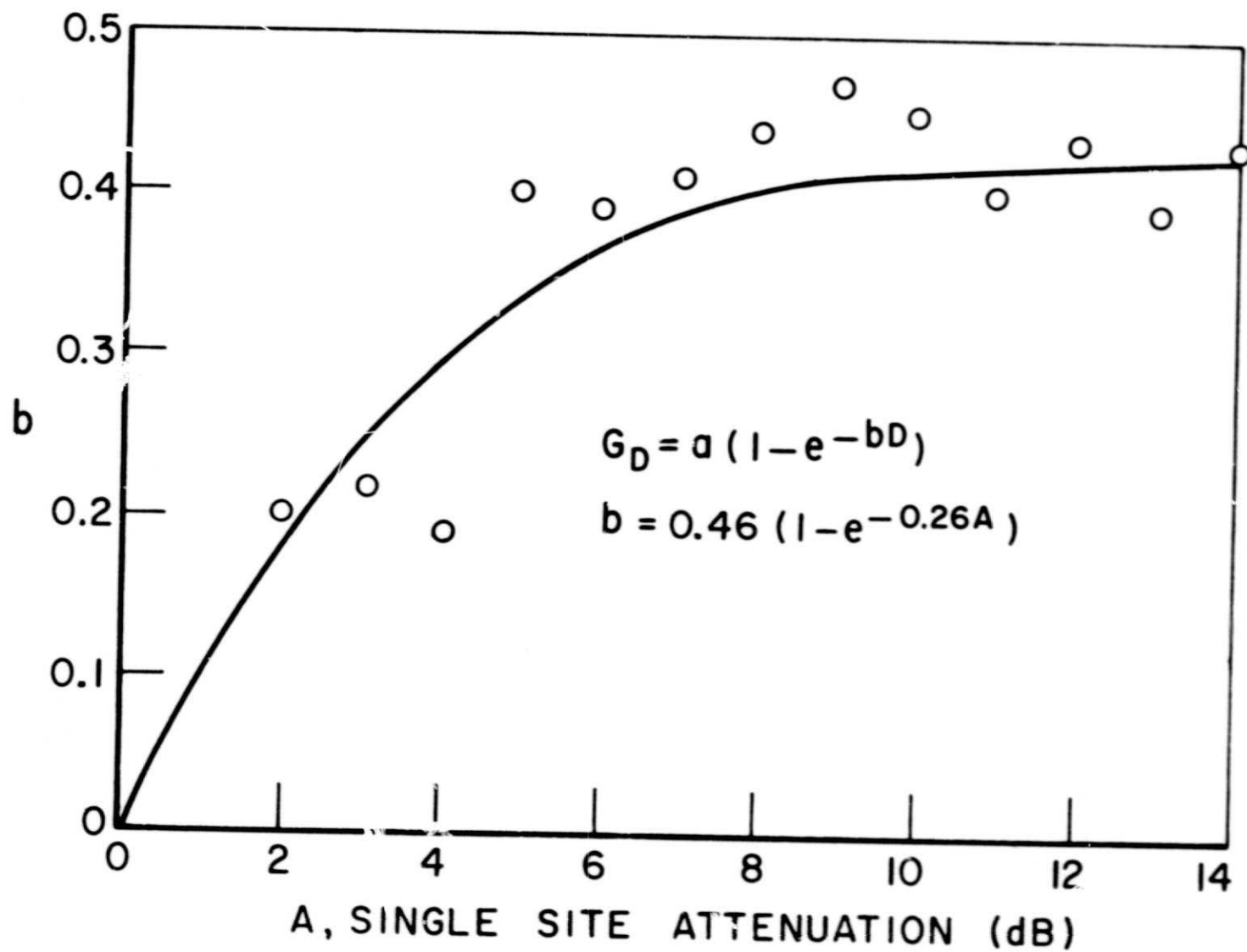
$$G_D = a(1 - e^{-bD})$$

$$b = 0.46(1 - e^{-0.26A})$$

Fig. 3. Coefficient b versus single sit attenuation, A.

worst approximately 0.75 dB. This agreement is well within the experimental accuracy of the experiment and emphasizes the consistency of these experimental data.

It is of interest to note that the linear portion of the curve relating the coefficient a to the single terminal fade depth intercepts the ordinate at about -3.6 dB. This coefficient may be interpreted as the difference between the diversity gain reached for large separation distances and the ideal diversity gain. Therefore, this result indicates that the diversity gain approaches a level approximately 3.6 dB below the ideal diversity gain as the terminal separation distance becomes large. This behavior is in accord with the concept of optimum diversity gain presented earlier [1].

It is also of interest to note that the coefficient b approaches a value of approximately 0.4 for large fade depths. This coefficient may be interpreted as the decay rate for diversity gain as a function of terminal separation distance. Thus, one may conclude that diversity performance is largely determined by storm cell cores having diameters on the order of 2.5 km.

Finally, the empirically calculated diversity gain is presented as a function of single terminal fade depth in Fig. 4. These curves show that the diversity gain has approached its optimum value, i.e., that value associated with an infinitely large separation distance, within 1 dB for terminal separation distances over 8 km.

II. PRELIMINARY ATS-6 30 GHz DIVERSITY DATA

The OSU participation in the ATS-6 Millimeter Wavelength Propagation has been described in an earlier report [2] and will only be summarized here. The primary objective of this experiment consists of 20 and 30 GHz downlink attenuation and radiometric temperature measurements at two spatially separated ground terminals. These terminals, the OSU Fixed and Transportable Terminals, were described in detail in earlier reports [3,4]. 20 GHz radiometric temperature measurements were also made at a third spatially separated ground terminal, the OSU Unmanned Terminal. In addition, a Comsat 12/18 GHz uplink terminal was colocated at the OSU Fixed Terminal along with three remote 18 GHz uplink Comsat terminals. The relative locations of these ground terminals are shown in Fig. 5. The nominal look angles to the ATS-6 synchronous satellite were 40° elevation and 200° azimuth.

Although a considerable amount of data has been collected at the present time, only initial results for 30 GHz diversity behavior have been analyzed to date. Hence, the following discussion covers only 30 GHz downlink attenuation data from the Fixed and Transportable Terminals.
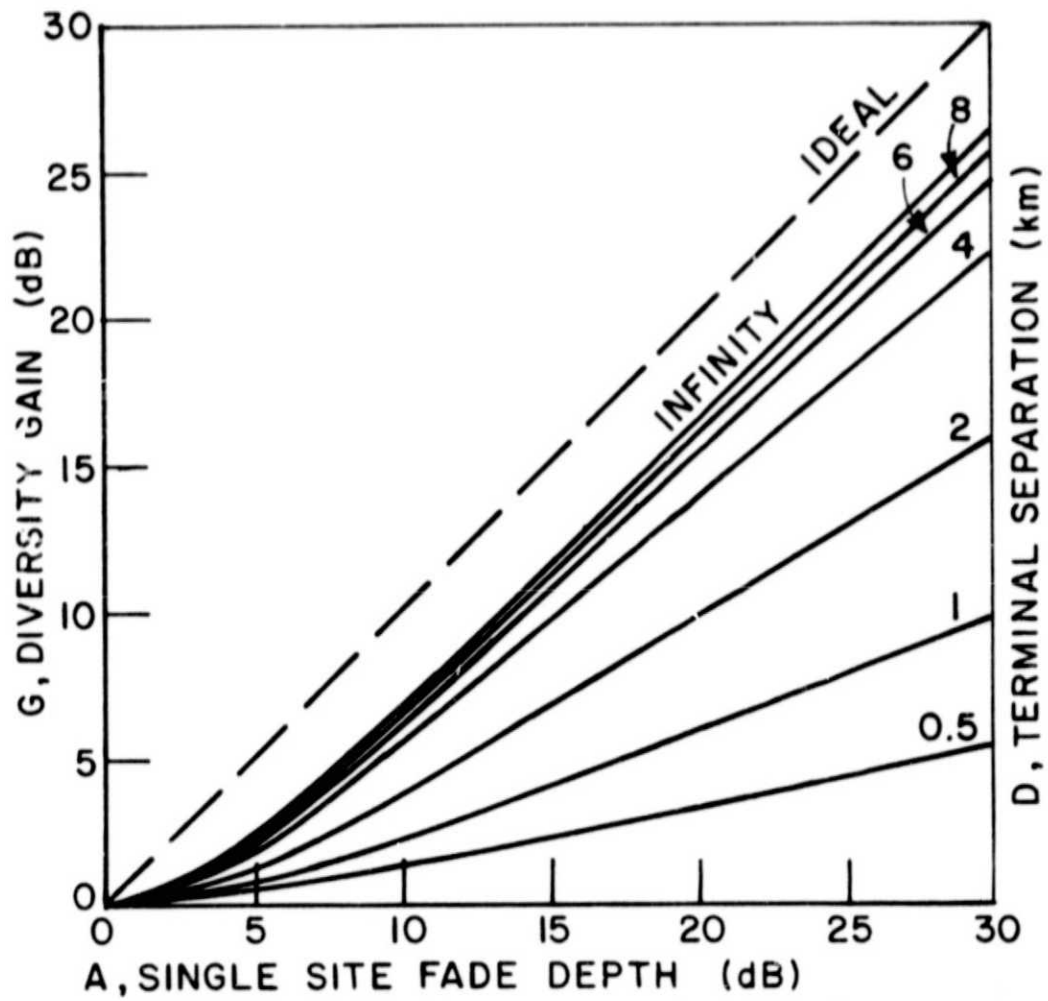
Fig. 4. Diversity gain, G, versus single
site fade depth, A.

NORTH

NOMINAL
SATELLITE
AZIMUTH

x O.S.U. TERMINALS
o COMSAT TERMINALS

20 + 30 GHz
RCVR / RADIOM
X

13.2 Km

13.8 Km

39.6 Km

28.0 Km

14.0 Km

5.2 Km

O

O

18GHz
XMTR

18 GHz
XMTR

x
20 GHz
RADIOM

o
18 GHz
XMTR

ox
20 + 30 GHz
RCVR / RADIOM

13 + 18 GHz
XMTR

OHIO STATE UNIVERSITY
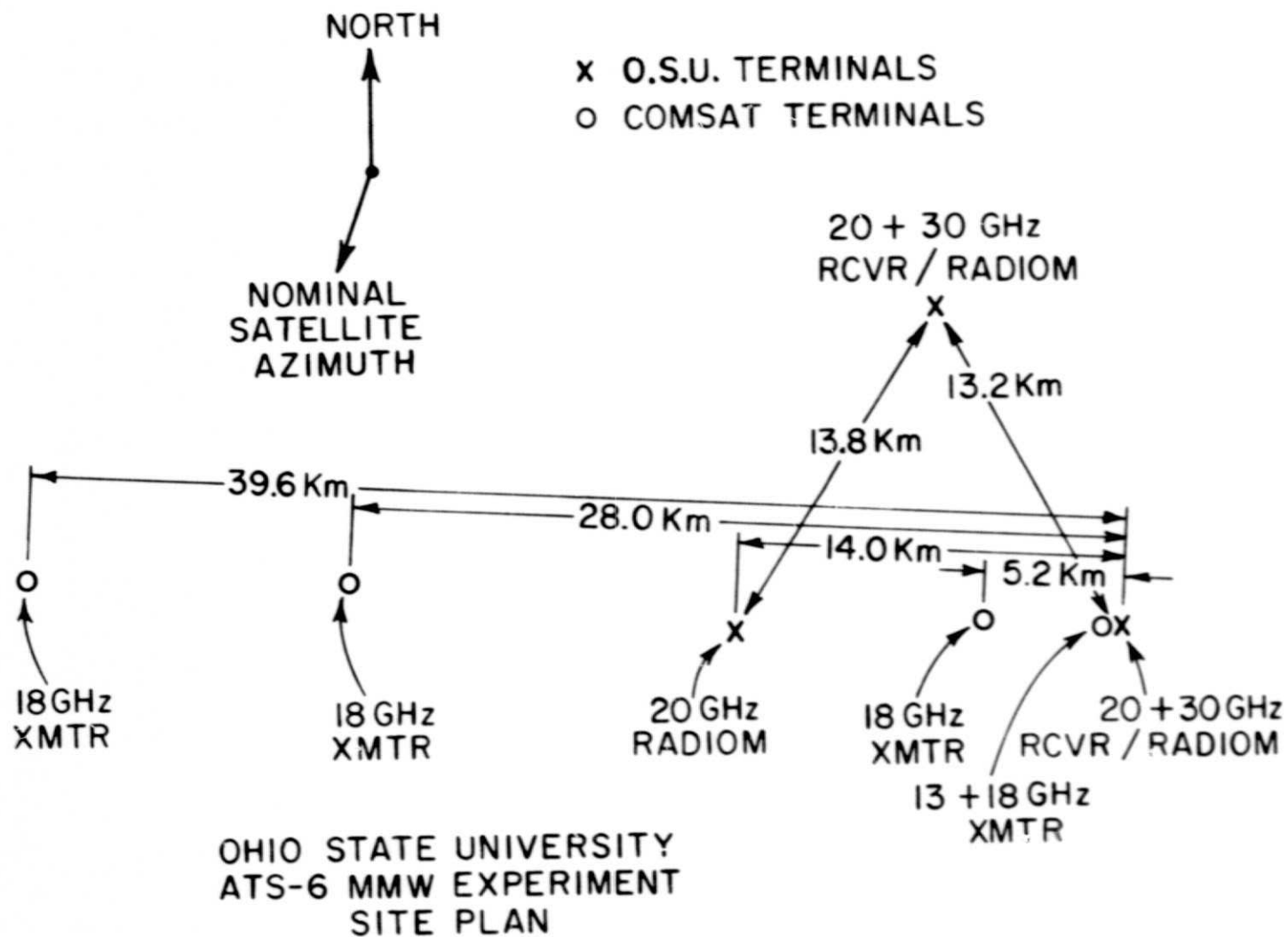ATS-6 MMW EXPERIMENT
SITE PLAN

Fig. 5. Ground terminal site plan.

Samples of the raw data from these terminals are presented in Fig. 6. These curves represent the sampled outputs of the 30 GHz receivers
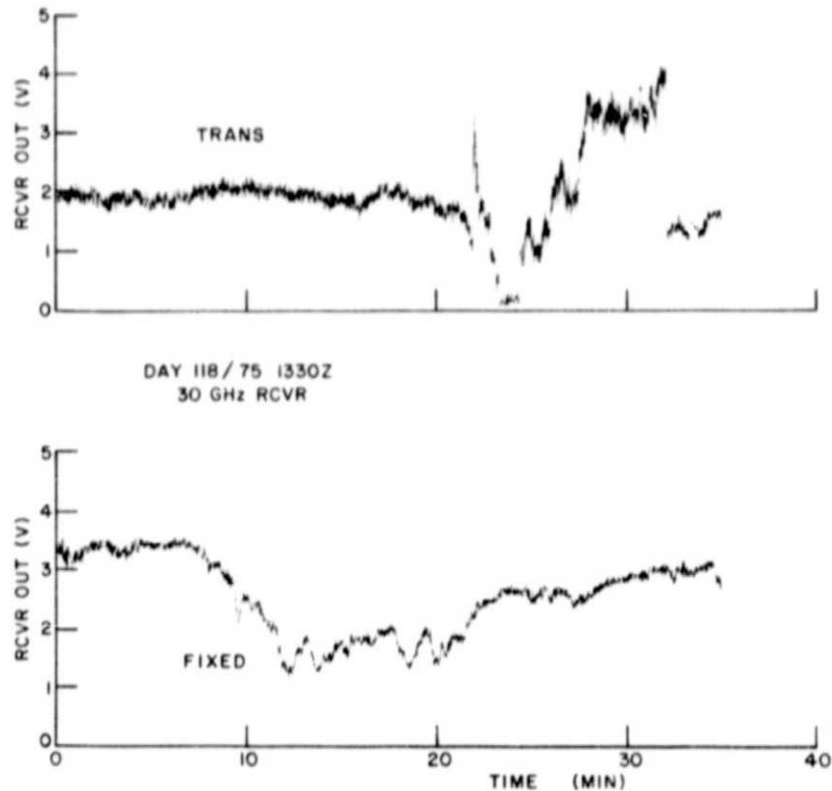

Fig. 6. 30 GHz raw receiver data (28 April 1975).

before processing. The receiver outputs were sampled at a rate of 10 Hz although the plots were generated using 10 sample, i.e., 1 sec., averages. It should be noted that at approximately 22 minutes into this data period a 10 dB pad was switched out of the receiver input at the Transportable Terminal. The received signal at that terminal subsequently dropped below threshold for approximately 1 minute, and the 10 dB pad was reinserted at about 32 minutes into the data period. This same segment of data is shown in Fig. 7 after conversion to a decibel scale and compensation for the pad changes. Finally, fade distributions were generated for this same data segment; these curves are shown in Fig. 8.

A set of cumulative fade distribution for seven fade events which occurred during early Spring, 1975, are presented in Fig. 9. It is
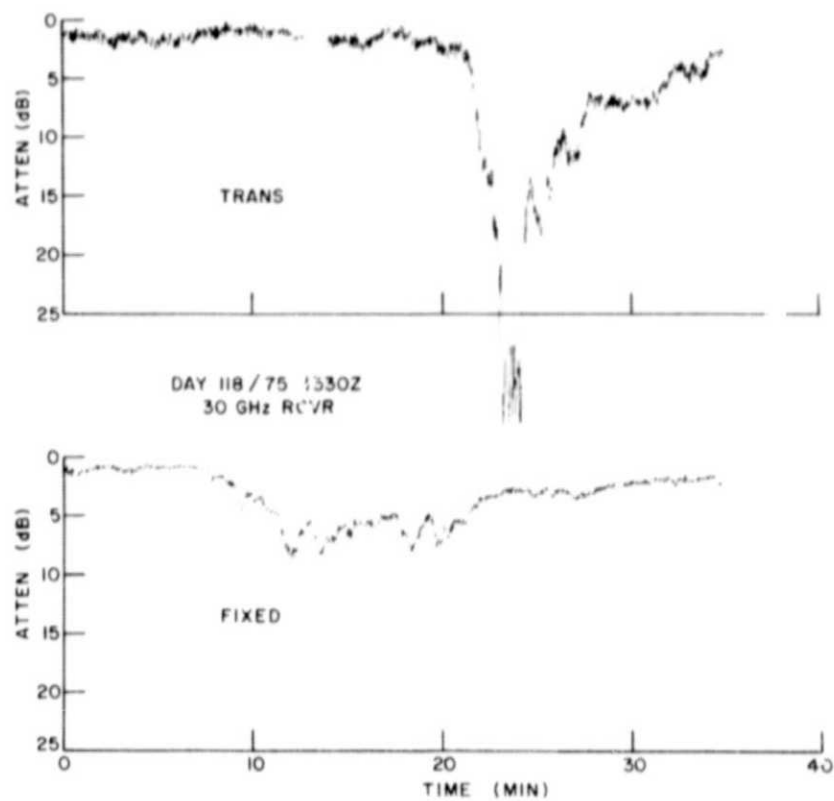
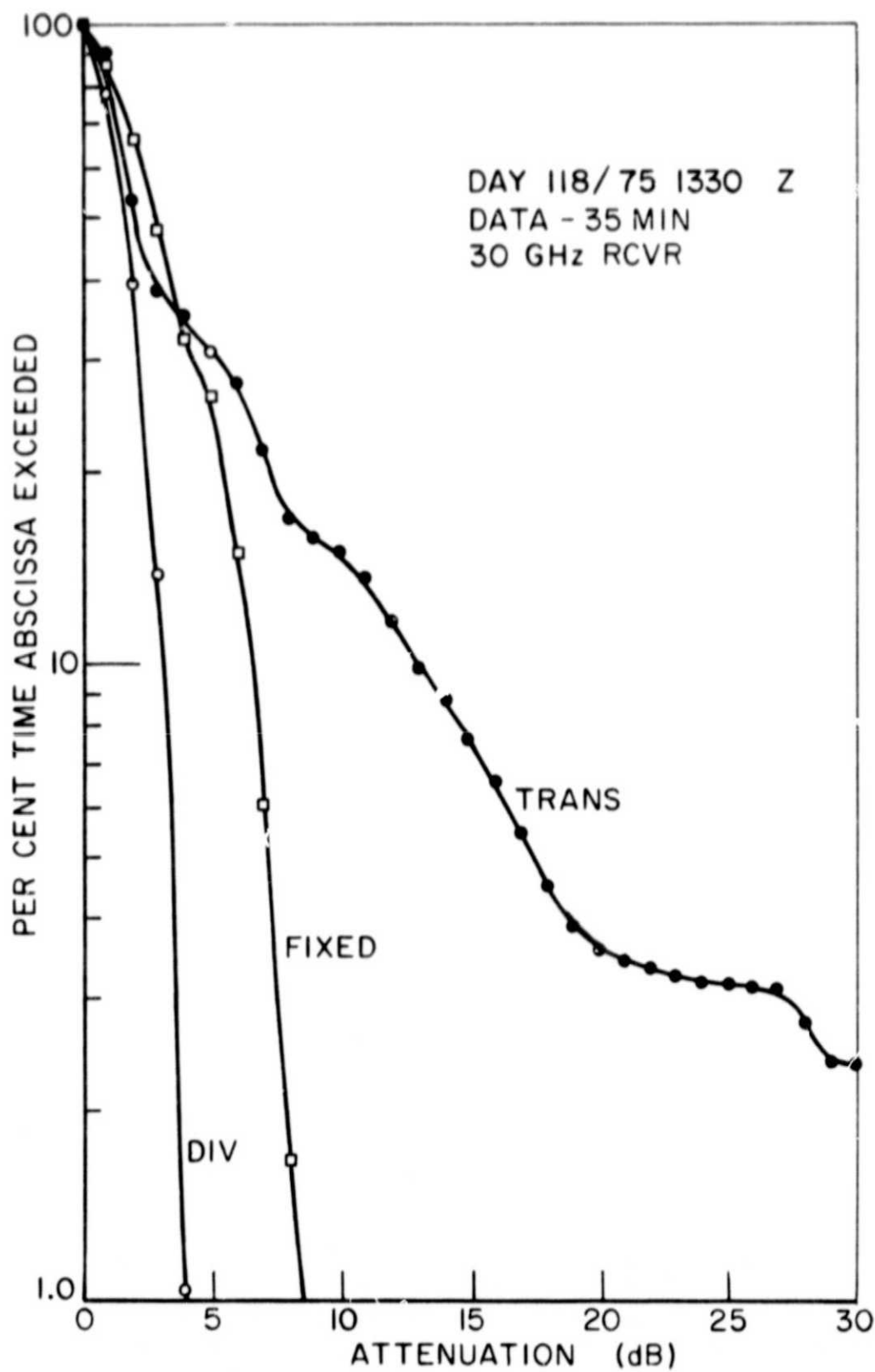Fig. 7.   Preprocessed 30 GHz receiver data (28 April 1975).

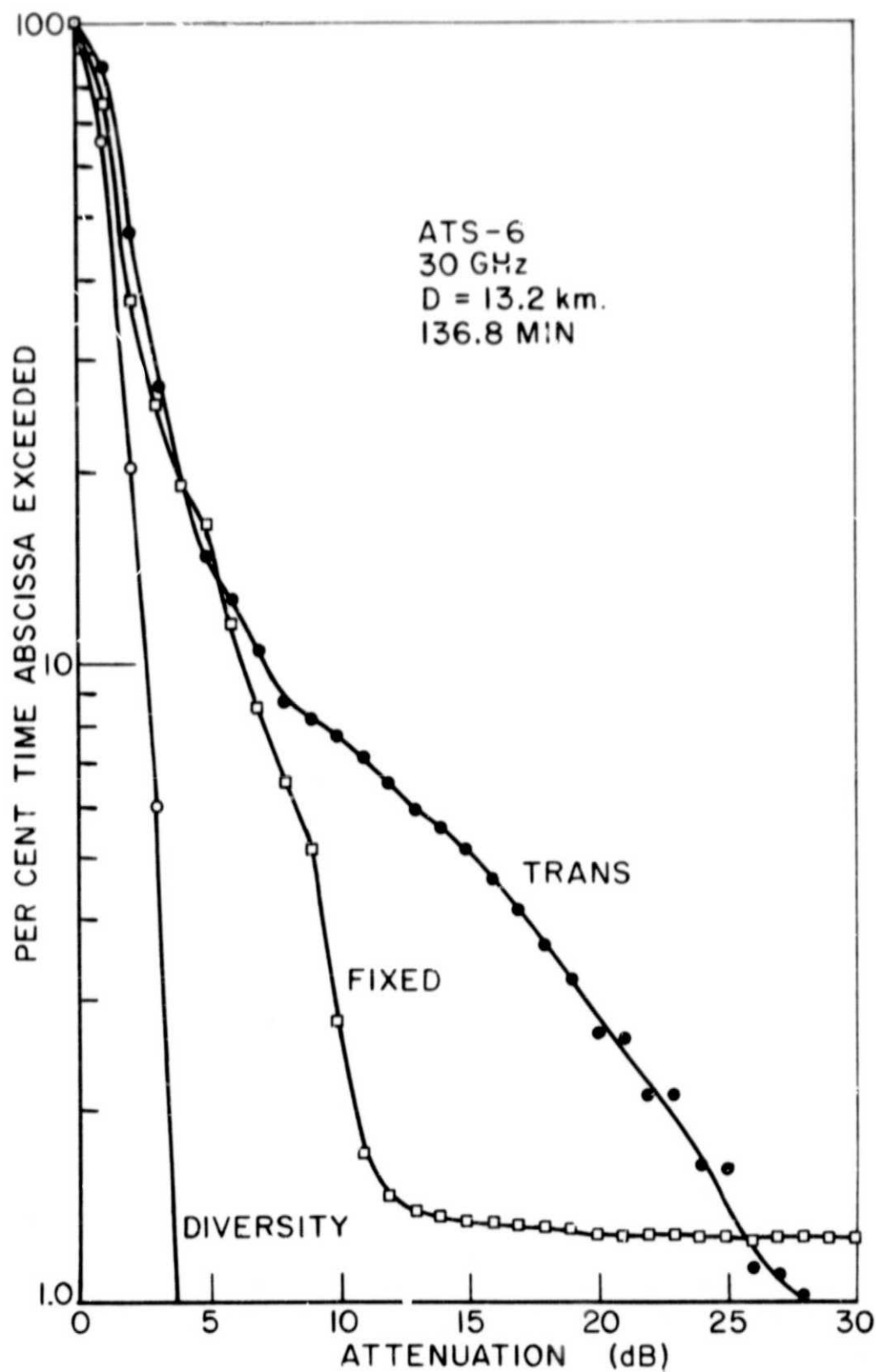Fig. 8.   30 GHz fade distribution (28 April 1975).

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Fig. 9. Cumulative 30 GHz fade distributions (7 events).

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interesting to note that the character of the diversity fade distri-
bution has changed little from that shown in Fig. 8 even though six
additional fade events are included. Both terminals experienced fades
to depths of 30 dB or more during one or more of these events.

Diversity gain data were extracted from the curves shown in Fig. 9;
these 30 GHz diversity gain data points are shown in Fig. 1 along with
the empirically derived diversity gain curves. The agreement is excep-
tional; in fact, although not shown in this figure, the 30 GHz data
points and the 15 GHz empirical results agree within 0.25 dB for all fade
depths up to 30 dB. The calculations were not carried beyond this fade
depth due to lack of data.

This preliminary result indicates that diversity gain is not a
sensitive function of frequency. Alternatively, this result indicates
that terminal separation distances of 8-10 km, which provide nearly
optimum diversity gain at 15 GHz, will provide the same diversity improve-
ment at 30 GHz. Clearly, this preliminary conclusion rests on a limited
data base at the present time; nevertheless, the close agreement with
earlier results tends to strengthen the credibility of this conclusion.

III. SUMMARY OF OPERATIONS

All three OSU ground terminals remain operational. The total
operating times as of 15 May 1975 were

Transportable	20 GHz	5,087 min.
	30 GHz	7,078
Fixed	20 GHz	3,957
	30 GHz	5,387
Unmanned		2,272
Total time		23,781 min.

Margin measurements were performed on 6 June 1975 with the satellite
antennas directed toward VPI. The margins were

	20 GHz	30 GHz
Transportable	46 dB	34 dB
Fixed	47 dB	37 dB

for the 20 GHz cw/Dish and 30 GHz cw/Horn modes.

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IV. CURRENT STATUS

Data collection is continuing at all terminals; it is anticipated that data collection will cease on about 13 June 1975 as the satellite moves out of view of the OSU terminals. Data processing is underway and will continue.

V. REFERENCES

1. D. B. Hodge, "Path Diversity for Reception of Satellite Signals," Journal de Recherches Atmospheriques, V. 8, p. 443, June, 1974.

2. D. B. Hodge, "ATS-F Millimeter Wavelength Propagation Experiment," Report 3863-1, July 1974, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering; prepared under Contract NAS5-21983 for National Aeronautics and Space Administration (NASA Goddard).

3. D. B. Hodge and R. C. Taylor, "ATS-6 Millimeter Wavelength Propagation Experiment," Report 3863-2, September 1974, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering; prepared under Contract NAS5-21983 for National Aeronautics and Space Administration (NASA Goddard).

4. D. B. Hodge and R. C. Taylor, "ATS-6 Millimeter Wavelength Propagation Experiment," Report 3863-3, March 1975, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering; prepared under Contract NAS5-21983 for National Aeronautics and Space Administration (NASA Goddard).

VI. PUBLICATION SUMMARY

This summary includes all reports, oral presentations, and publications generated under NASA Contract No. NAS5-21983.

1. 3863-1, July 1974

2. 3863-2, September 1974

3. 3863-3, March 1975

4. 3863-4, April 1975

5. "An Empirical Relationship for Path Diversity Gain," D. B. Hodge, submitted to the IEEE Transactions on Antennas and Propagation for publication.

6. "Initial Results of OSU 20 and 30 GHz ATS-6 Propagation Measurements," D. B. Hodge and D. M. Theobold, presented at USNC/URSI Meeting, Urbana, Illinois, 3-5 June 1975.